



Neutron Imaging Camera

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Neutron Imaging Camera

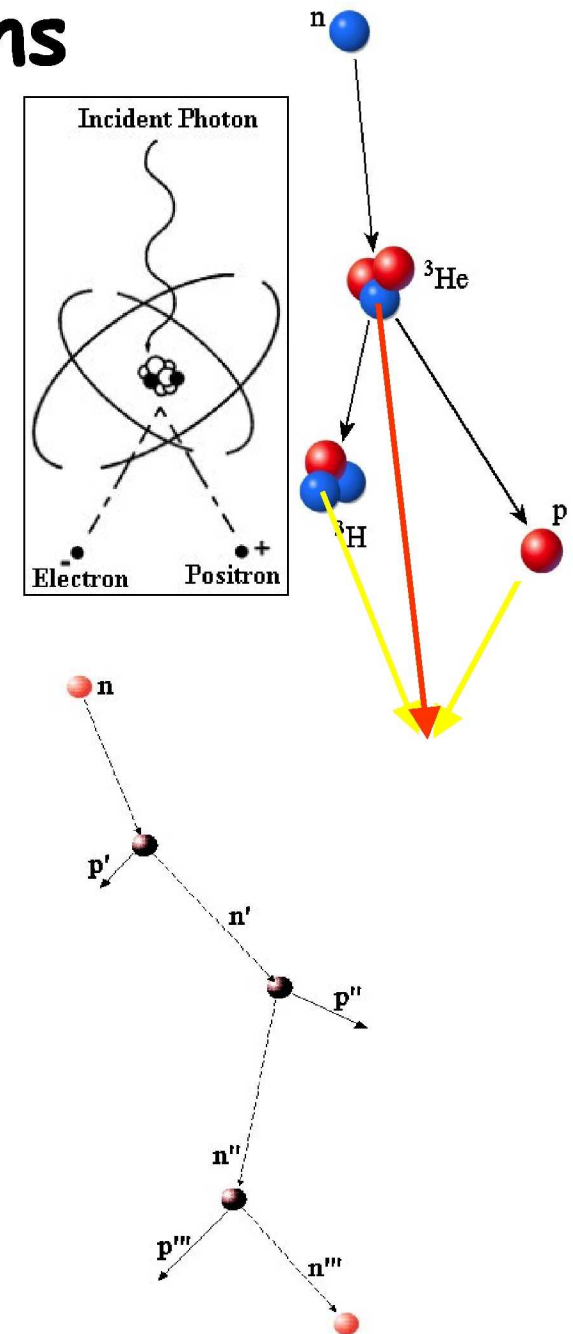
- Basis of NIC technology is 3-D tracking of charged particles in a gaseous medium.
 - Comprised of a Time Projection Chamber (TPC) with 2-D Micro-well readout (MWD).
- Unique technology; distinct from traditional methods for neutron imaging.
- Versatile Applications
 - Passive and active standoff interrogation
 - Space/Solar physics
 - Neutron, gamma, & charged particle detection

Methods of Neutron Imaging

- As with gamma-ray imaging, neutron imaging relies on the detection of secondary products of neutron interactions in matter.
- Take advantage of interactions with large cross sections:
 - Inelastic : ${}^3\text{He}(n,p){}^3\text{H}$
 - Elastic : (n,p)
- Use measured quantities from secondary tracks (arrival time, $(x,y,z), \vec{p}, E$) to reconstruct initial direction & energy of neutron.

Neutron Interactions

- $^3\text{He}(n,p)^3\text{H}$
 - Track p & ^3H
 - Vertex identification allows for reconstruction of *initial neutron momentum vector*
- Elastic (n,p) scatter
 - Track single & multiple scatter protons
 - Use \vec{p}_p to reconstruct initial neutron momentum vector
- Key to NIC technology is measuring secondary by-product *momentum vectors*.



NIC Advantage for (n,p) tracking

- Measure proton energy, E_{p1} & E_{p2}
 - + Interaction locations, L_1 & L_2
 - 1 scatter \rightarrow neutron detection
 - 2 scatters $\rightarrow 2\pi$ sr location, $E_n > E_{p1} + E_{p2}$
 - + **Momenta of scattered protons**
 - \rightarrow **Energy and direction of neutron**

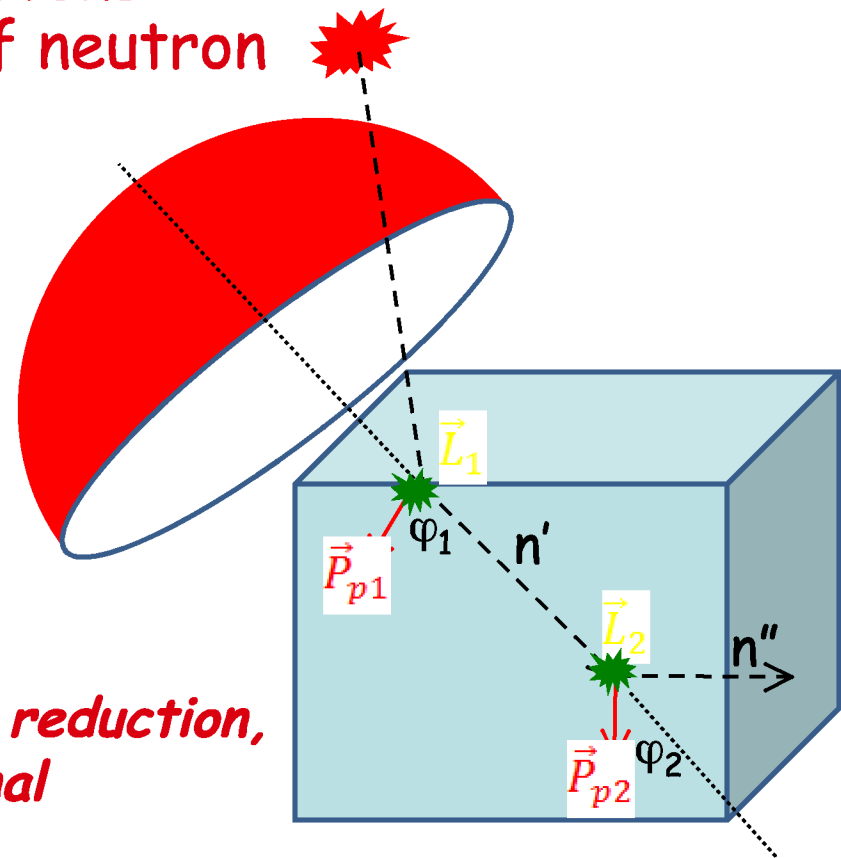
$$\cos \varphi_2 = \vec{P}_{p2} \cdot \vec{P}_{n'}$$

$$E_{n'} = E_{p2} / \cos^2 \varphi_2$$

$$\vec{P}_{n'} = \sqrt{2m_n E_{n'}} (\vec{L}_2 - \vec{L}_1)$$

$$\vec{P}_n = \vec{P}_{p1} + \vec{P}_{n'}$$

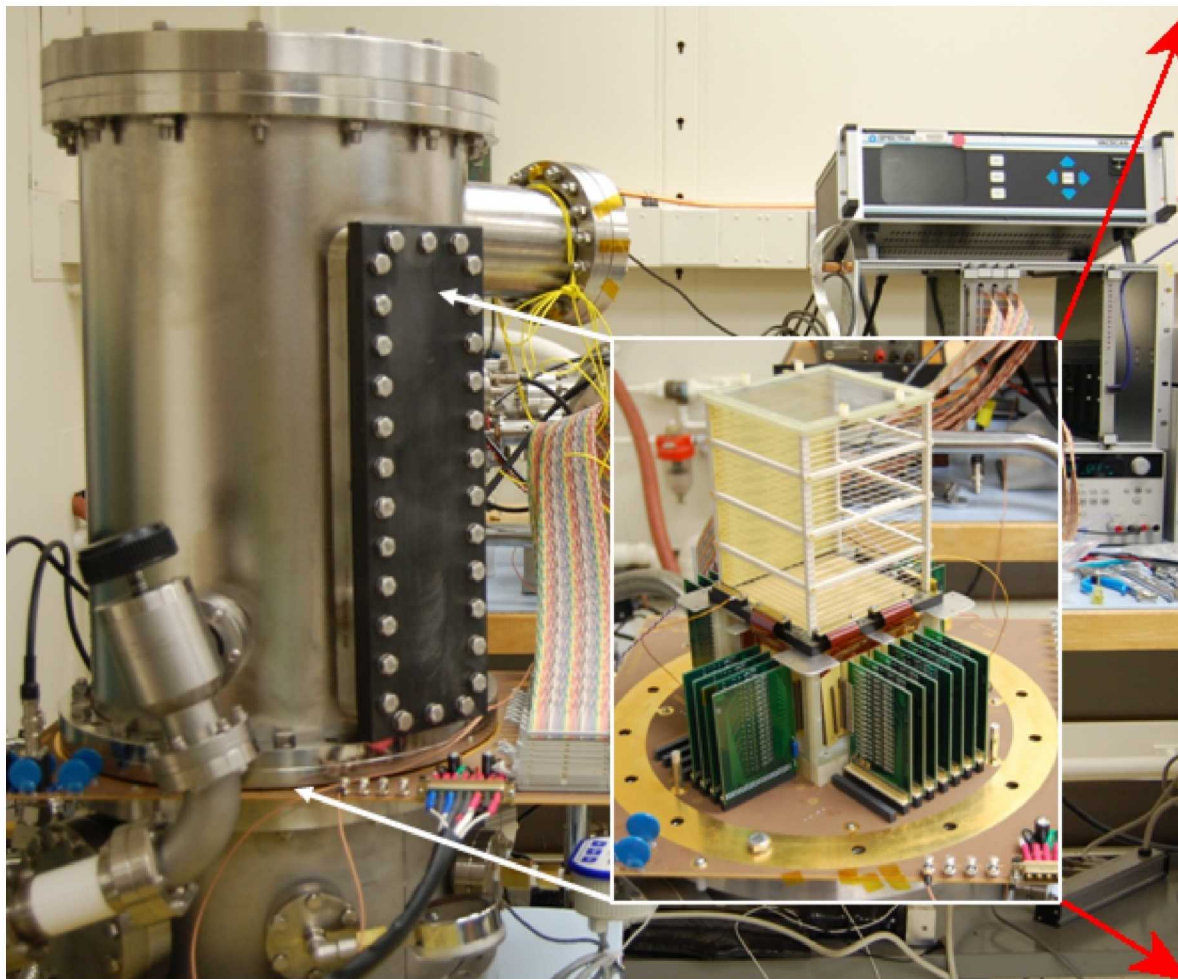
$$E_n = (\vec{P}_n \cdot \vec{P}_n) / 2m_n$$



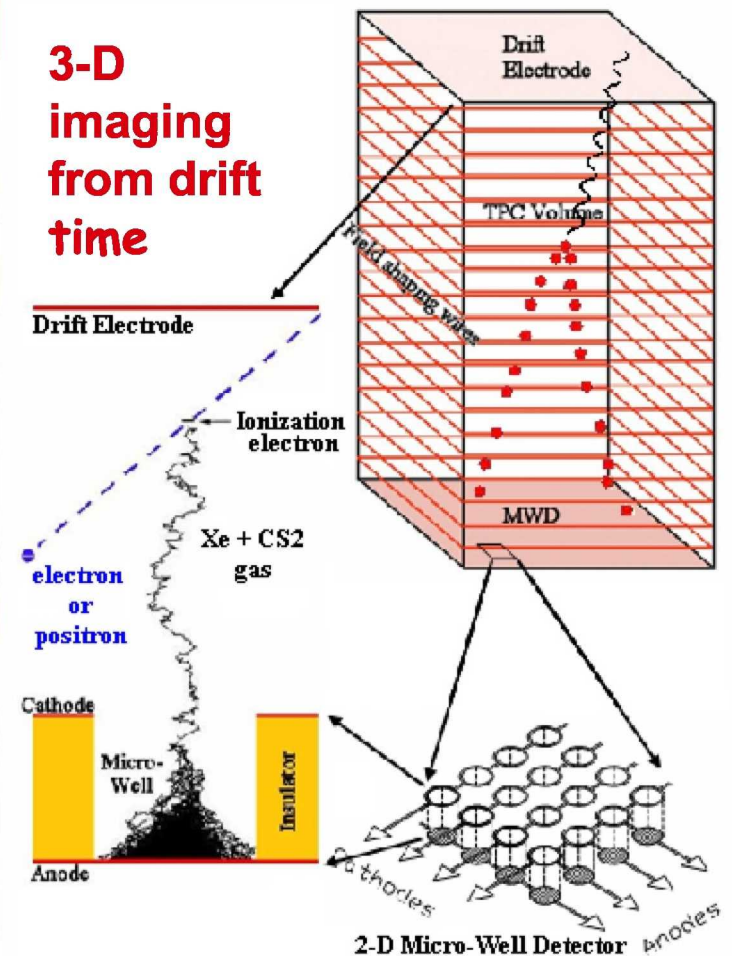
****Increase in sensitivity, background reduction, and angular resolution, omnidirectional***

NIC/3-DTI Theory of Operation

- **Ionization chamber:** Large-volume time projection chamber (TPC)
- **Proportional counter:** 2-D gas micro-well detector (MWD) readout
 - Low density, homogenous medium (low energy particle tracking)
 - 100 % active detector volume (no scattering in passive material)

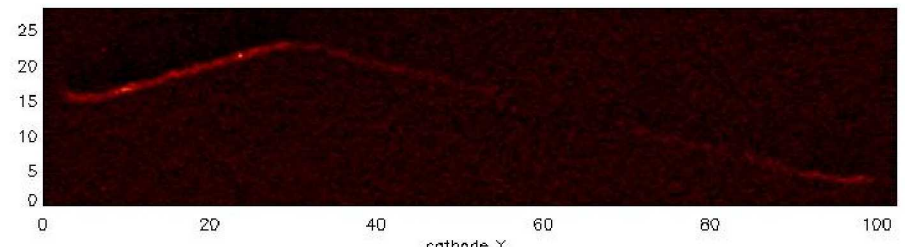
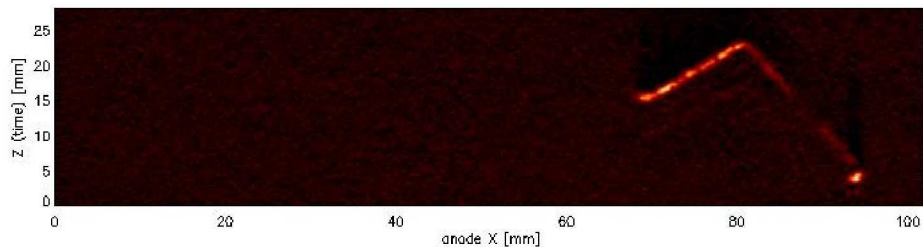
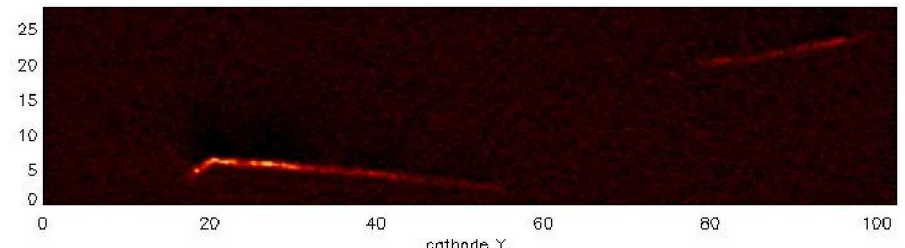
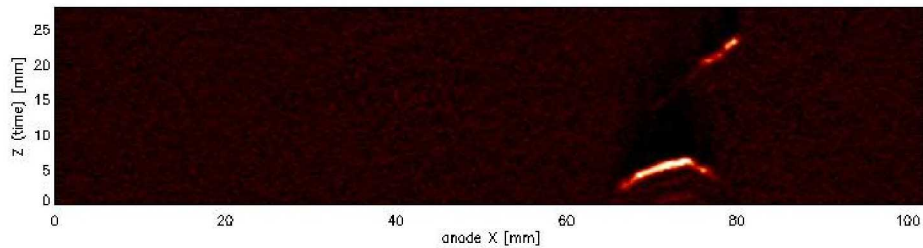
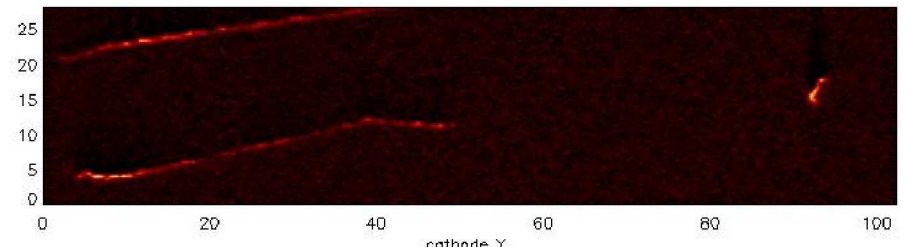
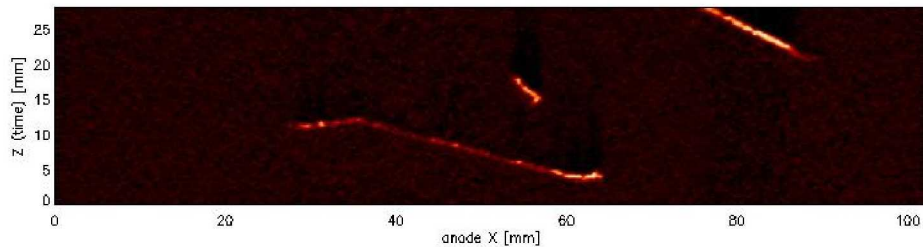
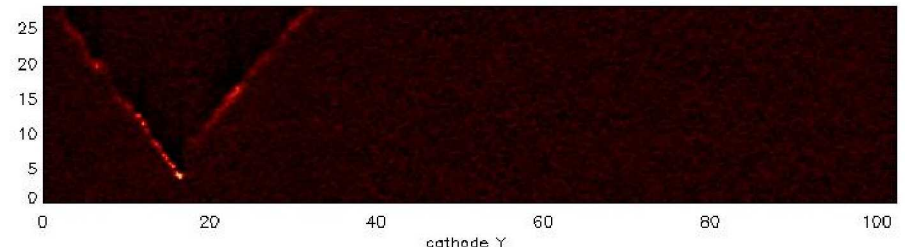
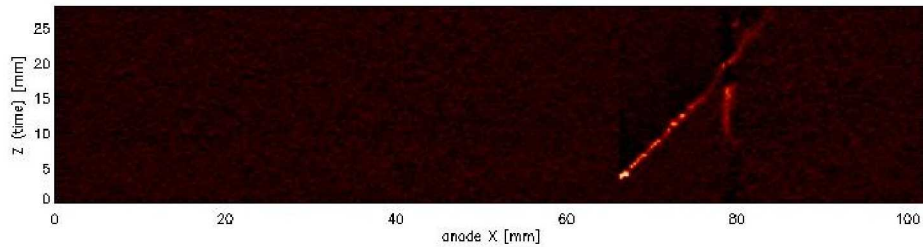


3-D imaging from drift time



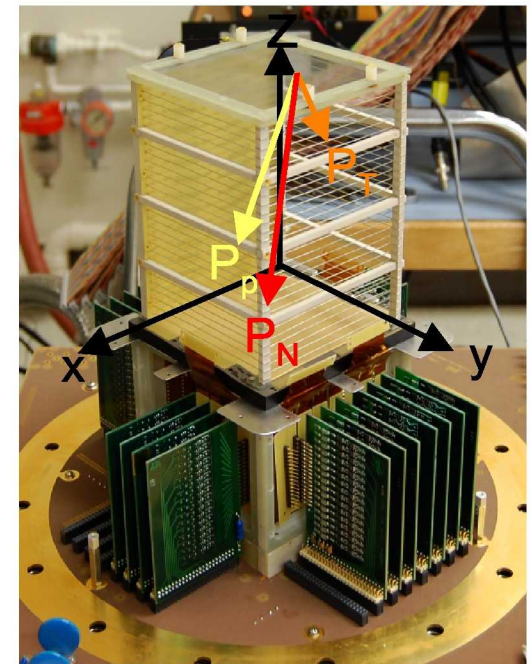
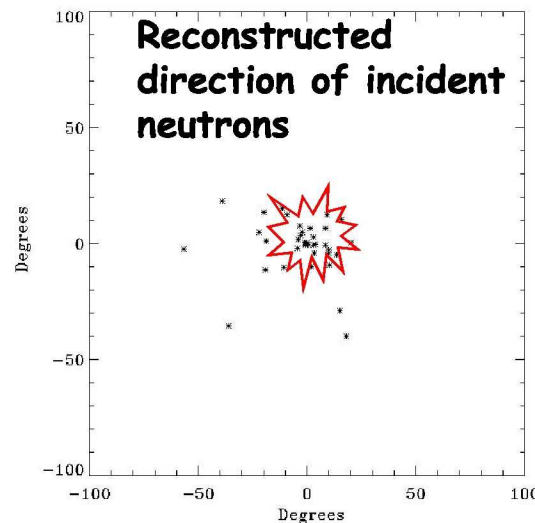
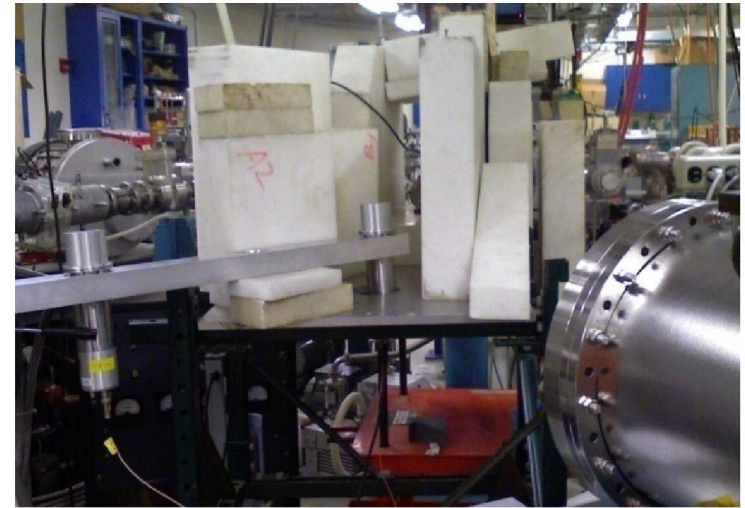
Successful NIC Demonstration

^3He based NIC



Neutron Imaging

- Imaged 1 MeV neutrons at the NSWC PIAF
 - Neutron momentum reconstructed from p,T fragments
 - Angular resolution $\theta_{68} \approx 8$ deg
- We are looking at alternatives to ^3He including H_2 & Methane-based NIC



MWD Construction

MWDs are "double sided flex circuit boards"
with orthogonal (2-D) traces on top & bottom.

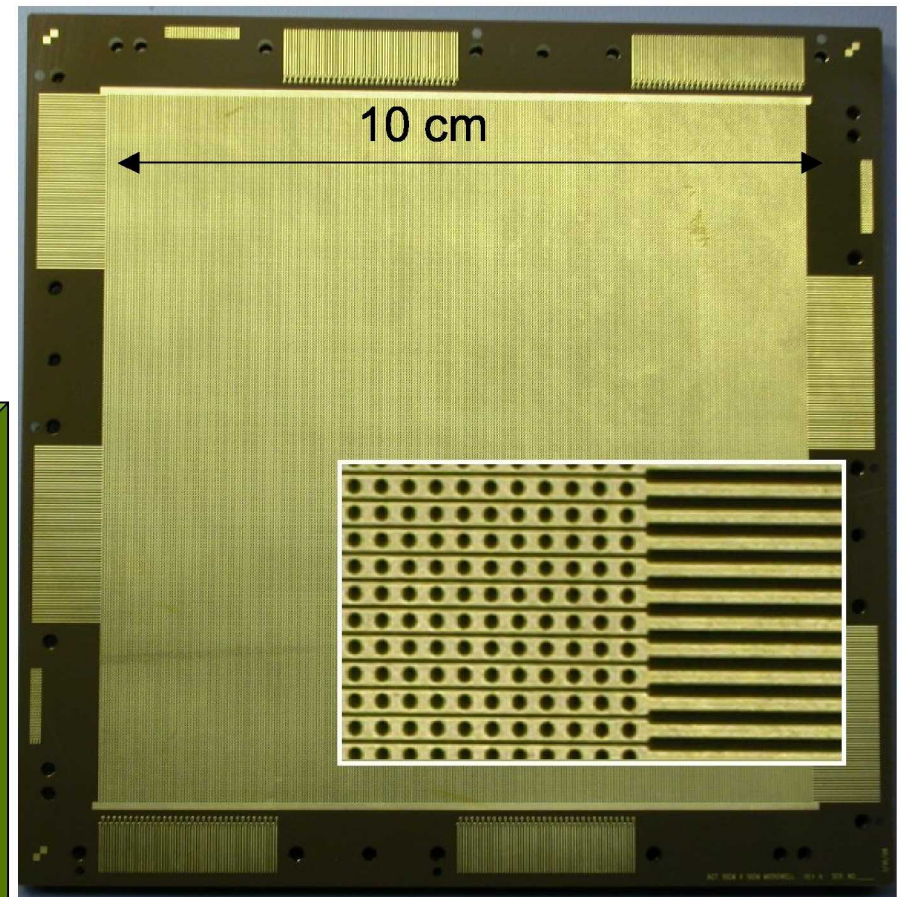
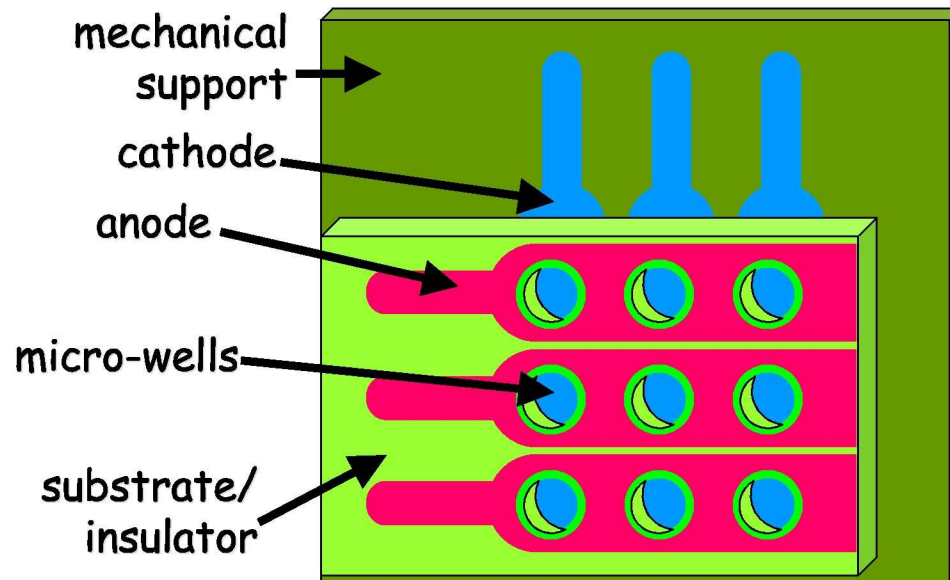
Micro-wells are holes, machined through substrate
concentric with openings in cathodes.

Well Pitch: $400\mu\text{m}$ (16 mil)

Well Diam: $200\mu\text{m}$ (8 mil)

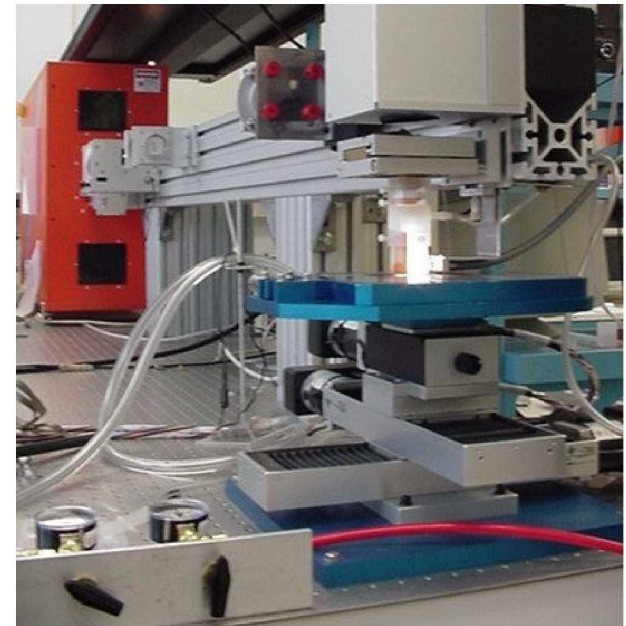
Well Depth: $200\mu\text{m}$ (8 mil)

Cathode Gap: $50\mu\text{m}$ (2 mil)
goal $12\mu\text{m}$ (0.5 mil)



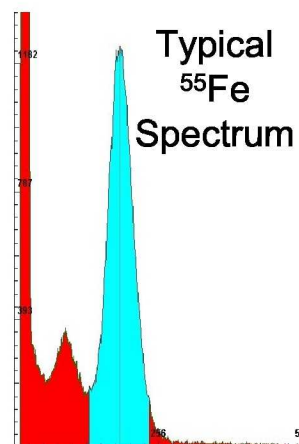
MWD Fabrication

- Laser micro-machining facility is fully functional
- Machining sections of $10 \times 10 \text{ cm}^2$ substrate area to optimize technique
 - Many aspects of fabrication effect MWD performance (gas gain)
 - Laser ablation technique
 - Surface cleaning
 - Well diameter wrt to cathode hole diameter
 - Well aspect ratio
- 1 Day turn-around
 - Rapid testing of techniques

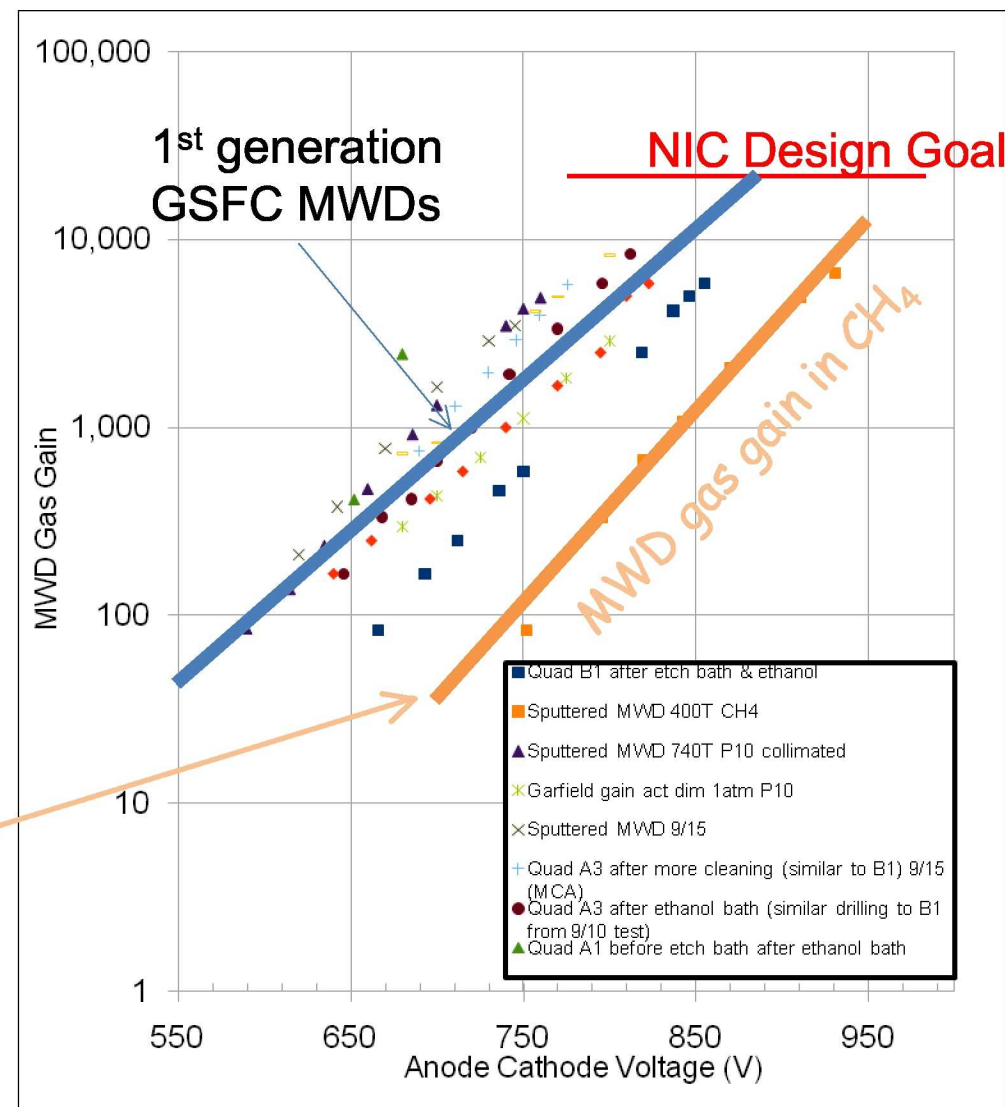


GSFC MWD Performance

- 2nd gen GSFC MWDs
- Gain measurement
 - Collimated ^{55}Fe source, P-10 at 1 atm
- Max gain limited by breakdown

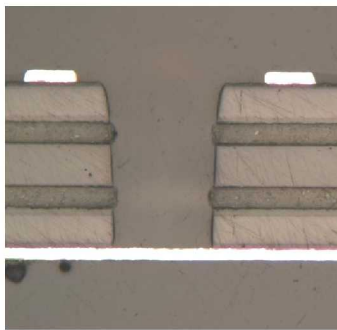


- Works with CH_4
 - V_{AC} higher
 - $\text{CH}_4 + \text{CS}_2$ tests soon

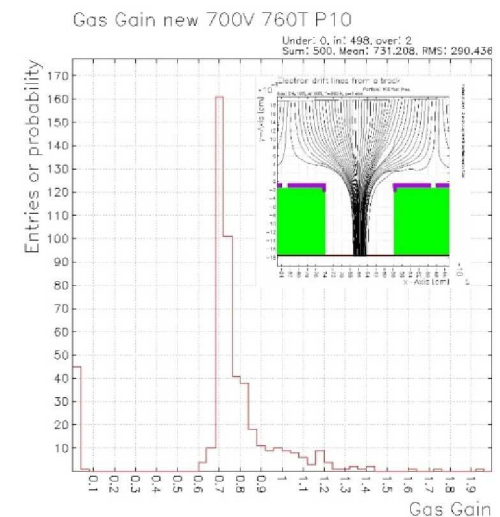
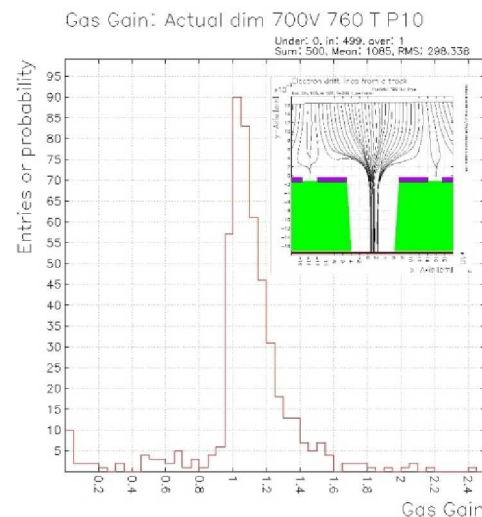
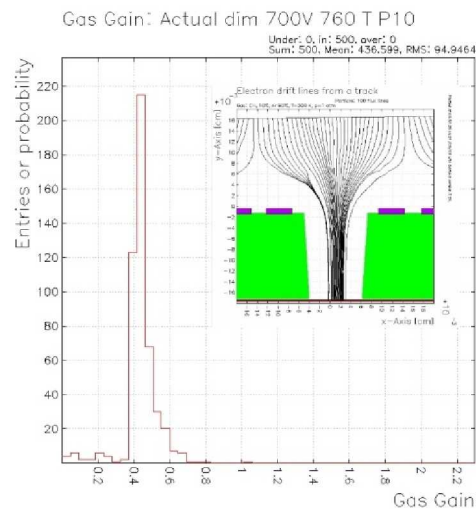
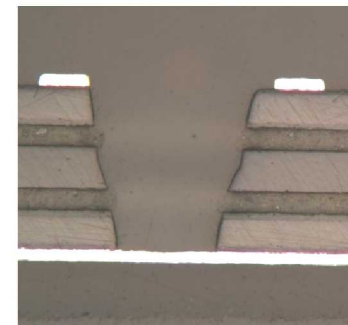


GARFIELD Simulations

- Model various gas mixtures and well geometries to optimize MWD performance and fabrication
- Results indicate strong dependence on well shape



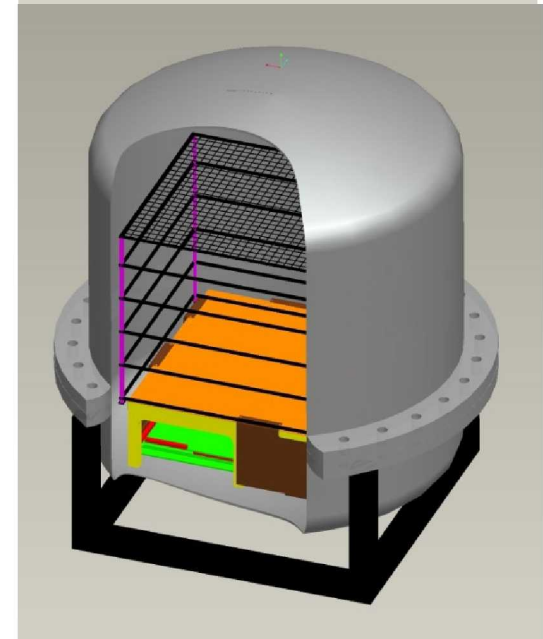
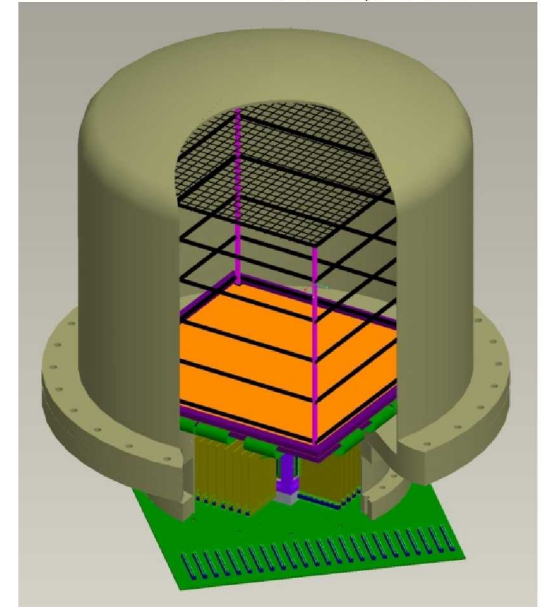
P-10 at 760 torr, $V_{Bias}=700V$
 400V drift potential
 Histograms from 500 Monte-Carlo
 electrons drifted from a line 200 μm
 above the center of the well



30x30 cm² NIC Development

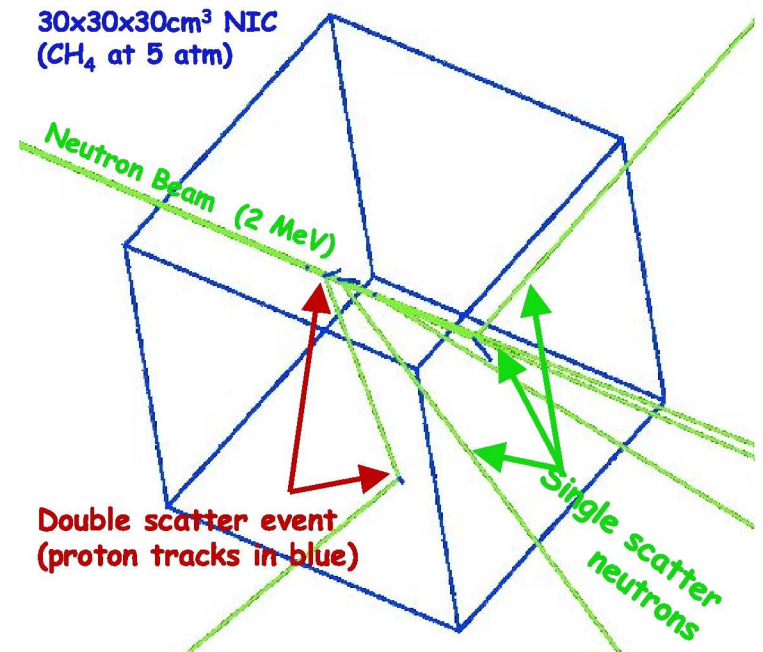
- Produce 30x30 cm² NIC for field testing by early 2010.
- 30 cm MWD with 10 cm electronics
 - 1/3 resolution readout (512 channels)
 - Gang 3 electrodes to one FEE channel
 - Snapshot and semi-streaming data mode
- 30 cm MWD with 30 cm electronics
 - 1/2 resolution readout (768 channels)
 - Every other electrode read out, limited by number of ASICs
 - Streaming data mode
- Full resolution readout (1536 channels)
 - Additional ASICs, not before Jan 2010

30cm NIC



GEANT4 Simulations

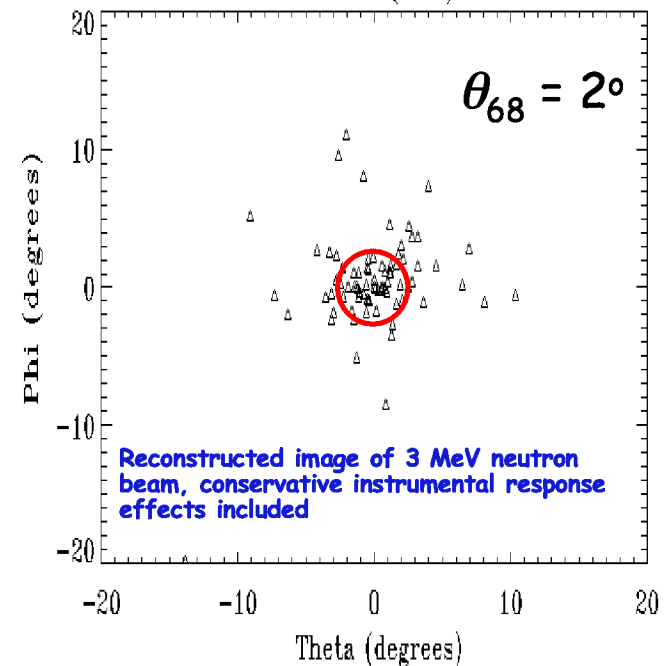
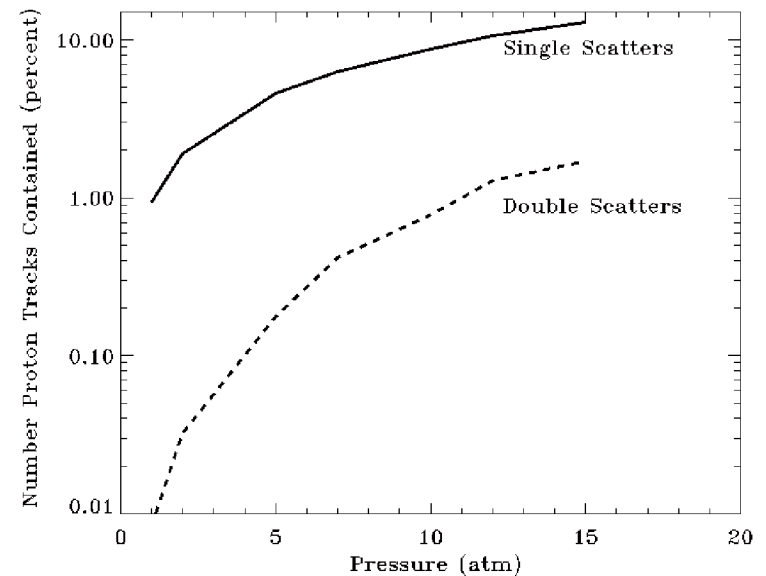
- Simulate (n,p) double scatter events within NIC
 - Assume NIC is filled with CH_4
 - Neutron beam:
 - Point source or uniform illumination
 - Mono-energetic or representative of a radioactive source, e.g. ^{252}Cf
 - Track all single & double scatter events
- Generate simulated events for image reconstruction software development
- Reconstruct image plane using simulated events
 - Add instrument response



NIC Efficiency Estimate

30 cm NIC, 3 MeV neutrons

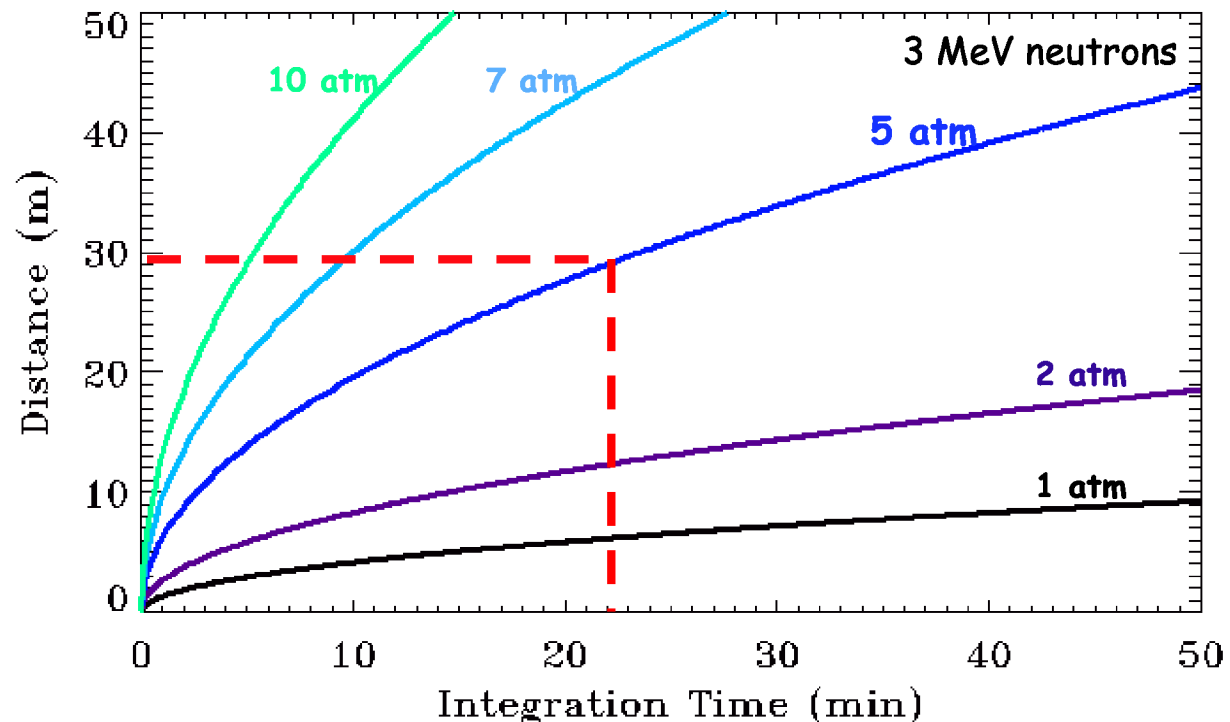
- Probability of interaction $\sim 0.5\%$
- ^3He at 3 atm
 - Single interaction, PSF: $\theta_{68} = \sim 5^\circ$
- CH_4 at 5 atm
 - Double scatter, PSF: $\theta_{68} = \sim 2^\circ$
- Imaging reduces contribution of the background
- Improves sensitivity



NIC Sensitivity

- Evaluate NIC sensitivity to 20 microCi ^{252}Cf source.
- Consider Omnidirectional NIC (all four sides of square 30x30x30 cm² active volume).
 - Compute cosmic ray background intensity accounting for zenith dependence (Moser et al. 2005).
 - Assume 25 square degree resolution within field of view, resulting in ~1100 pixels over entire field of view
 - Assume NIC properly identifies every interacting neutron and choose only proton tracks that are fully contained with NIC
- ***Determine the integration time versus source location such that NIC identifies a source with a 1/1000 probability for false positive.***

* Trade Study underway to optimize NIC Sensitivity



NIC Field Testing

- NIC 30 cm prototype completed in early 2010
 - MWD Optimization (GARFIELD and empirical studies)
 - Gas studies for methane-based NIC
 - NIC design optimization based on GEANT4 simulations
- GSFC Field Tests
 - D-T generator
 - 10 mCi ^{252}Cf source
- NSWC Field Tests
 - D-T generator field tests
 - NSWC/PIAF tests
- ONR funding to investigate active and passive integration of NIC on Naval platforms